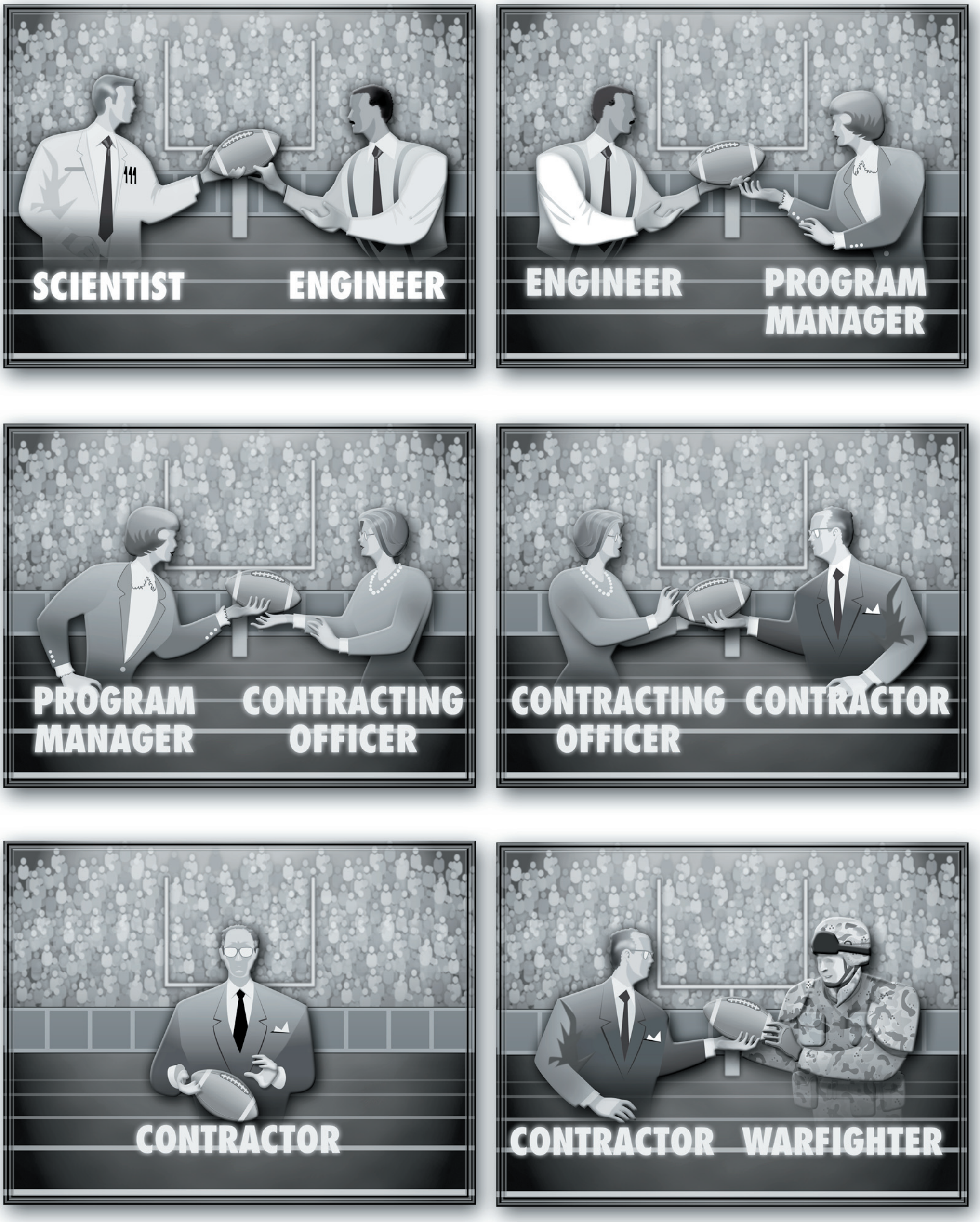

Image designed by James Elmore

Throughout the acquisition process there are numerous opportunities to drop the ball. Using sound business and systems engineering practices ensures essential information is passed to enable better performance and lower cost.

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TECHNOLOGY MANAGEMENT BEST PRACTICES: *REDUCING TECHNOLOGY IDENTIFICATION, EVALUATION, AND SELECTION COSTS*

Stephen J. Moretto

We live in an uncertain environment. Military requirements are constantly evolving to keep pace with advances in technology and changes in the forces that threaten Americans. Assessing the success and effectiveness of today's complex systems is becoming an increasingly challenging and costly problem. The services are being asked to increase performance and reduce lifecycle costs. By beginning with the end in mind and using existing tools as a starting point, stakeholders can contribute to reduced program support costs, better justification of source selections, and better end products. Examples will demonstrate how alternatives can be prioritized to fit within budget constraints, how to link capabilities to cost, and how to efficiently select the best value among competing complex systems.

Designing and placing a weapons system under contract is time-consuming and costly. It is done best when the diverse disciplines work in an integrated fashion. This article takes knowledge from the technical and acquisition communities and identifies tools, techniques, and processes than can enable them to work in a more integrated fashion. The technology selection process occurs near the beginning of the research and development process and is run by the technical community, while the source selection process occurs much later in the acquisition process. The two

processes have some commonality in that they use metrics to evaluate the value of technologies and proposals.

Time and cost in a proposal evaluation can be reduced by improving the linkages between technology evaluation and source selection processes. The cost of identifying, evaluating, and selecting weapon system technologies is measured in terms of government labor-hours expended, travel expenses, over-runs, delayed schedules, performance shortfalls, and missed opportunities. This article will identify some of the opportunities to improve organization, requests for proposals, and evaluation processes and criteria that are integral to the procurement of complex weapon systems.

The result of improvements will focus our resources on that which is of greatest value. The goal is to reduce both government and contractor labor-hours expended and improve communication between contractors and government. Improved communication will focus efforts on maximizing performance within budget constraints.

By beginning with the end in mind, the contractor can spend less time trying to interpret requirements, and spend more time focusing on design and delivery of products that offer more value for the dollar. Government costs shall decrease due to better-defined and automated processes. The government and contractor would also reduce program risks through more clearly defined contract performance requirements. The remainder of the article will describe the military requirement generation process, the technology and source selection process, and suggest improvements to these processes.

OVERVIEW OF REQUIREMENTS GENERATION

The weapons system acquisition process starts with the need for national and economic security, which translates into requirements for complex military systems with the capabilities to accomplish missions. As shown in Figure 1, requirements originating at the top level and science & technology programs originating at the bottom level lead to the development of integrated systems that accomplish our goals of national and economic security. The science and technology efforts form the foundation of the development process and become capabilities that are combined into national assets such as ships and planes. Technology identification, evaluation and selection go on at each level of system development.

This article asserts that the best results are achieved when a System-of-Systems approach is used. This is where you consider how all the pieces work together and optimize the system as a whole, instead of just focusing on subsystems. The challenge is getting both decision makers and subsystem designers to understand the interrelationships between subsystems and the effect of the performance on the whole system. For example, engine designers may want a big powerful engine, but if they get the space for the big engine, there may not be sufficient space for a gas tank large enough to enable the vehicle to perform the mission. This concept can be used at each level of system design.

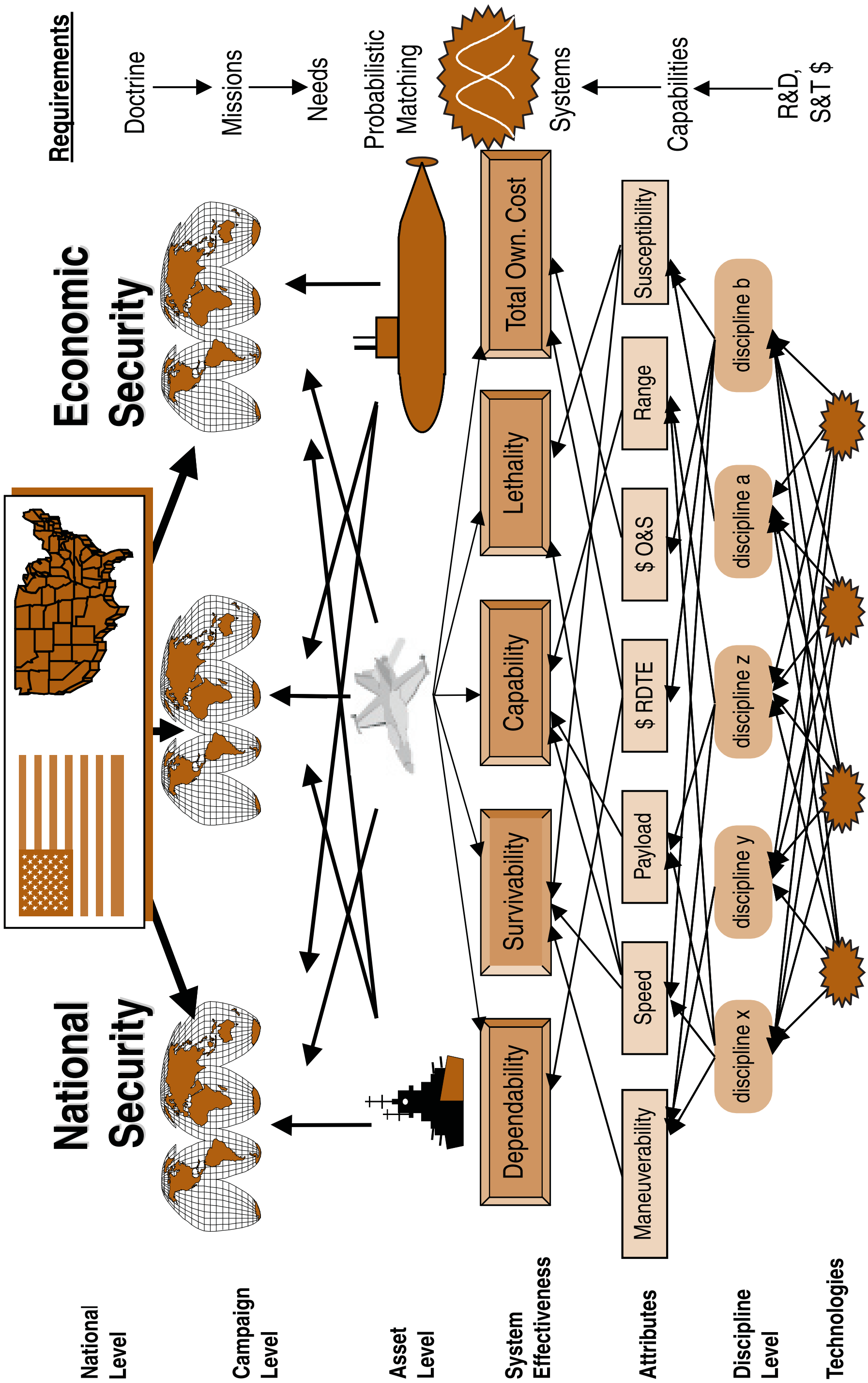

FIGURE 1. REQUIREMENTS GENERATION AND FULFILLMENT

PROBLEMS AND CHALLENGES

Assessing today's complex systems is becoming more challenging. Demands and constraints are increasing, despite relief from Department of Defense (DoD) acquisition process requirements. Figure 2 shows some of the demands and constraints in assessing today's complex systems. The challenge is to link the requirements generation process to the generation of the request for proposals (RFPs), and to incorporate performance-based standards into the RFPs and source-selection criteria.

SELECTION PROCESSES

Selection processes vary during the procurement of a weapon system. The DoD uses various systems to decompose top-level requirements, match them to systems, perform tradeoffs and select quantities of equipment to procure. The information flows up from the program office designers, who use detailed models to determine and select the best combination of capabilities within cost constraints. The best combination of capabilities is determined by using a requirements generation process that involves the technical community, users, and the program office. The technology identification, evaluation and selection process need to be performed early in the development cycle. This process generates detailed results that should be used later on in the procurement.

Source selection is the business side, a part of the contracting process, in which the government contracts department leads an effort to choose the best source to produce the weapon system. The contracting process starts with market surveillance to see what technologies and vendors are available on the open market. This is the best phase for

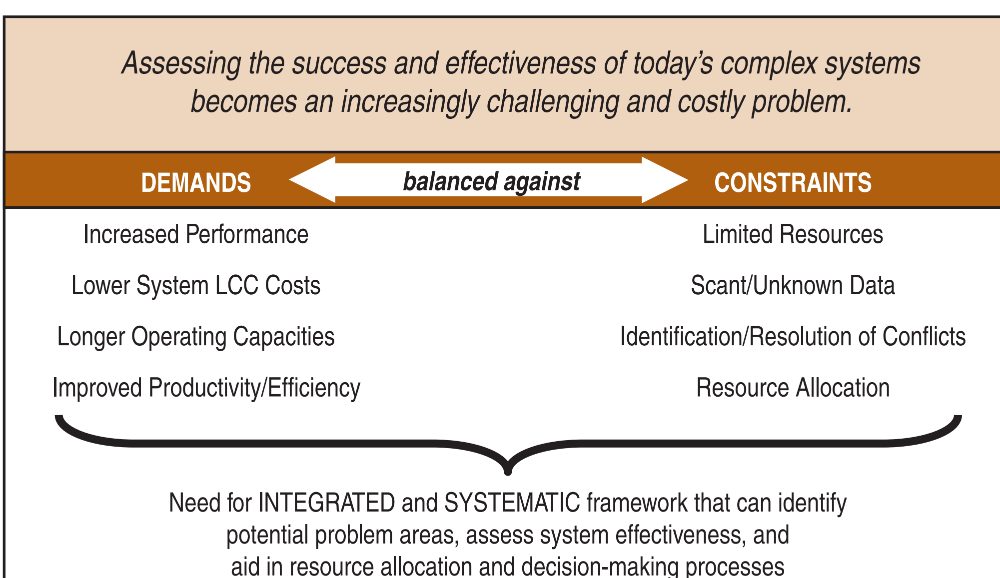

FIGURE 2. DEMANDS AND CONSTRAINTS

designers and engineers to become involved in the business side of the contracting process source selection because it allows the technical and contracting communities to use the results of the technology evaluation process throughout the contracting process.

After market surveillance, the contracts department prepares an RFP that is sent out for contractors to bid on, and the government then evaluates and selects the best proposal. One challenge is to get technical personnel involved in the front end to assist the contracts department in the preparation of the RFP and determination of source selection criteria. Using more detailed performance-based criteria would result in better proposals that could be evaluated efficiently (reducing labor by technical evaluators), provide better justification of source selection (reducing costs related to protests), and better contractor performance downstream (providing better cost and schedule performance due to better up-front understanding of requirements).

By beginning with the end in mind, DoD can reduce costs and end up with more effective systems. When technical experts are engaged later in the process, technical requirements and evaluation factors are less well defined, making it more difficult for contractors to understand, and more difficult for government personnel to evaluate. Source selection criteria have been limited in scope in the past because of the huge effort required to compile and integrate the results. Fortunately, processes and electronic tools have been developed to compile and integrate proposal evaluation results. Using these tools is sure to reduce cost and increase effectiveness of both the source selection and technology selection efforts. The remainder of the article will outline the processes and tools that can be used in any selection process.

REQUIREMENTS IDENTIFICATION AND DEFINITION PROCESS IMPROVEMENT

Systems engineering requirements analysis is a best practice in the DoD. DoDI 5000.2 states that "throughout the acquisition process the program office shall work to establish and refine operational design requirements that result in the proper balance between performance and cost constraints." Requirements analysis shall be conducted iteratively with functional analysis to develop and refine performance requirements and external interfaces. This also shall provide traceability to user and design requirements. The Technology Identification, Evaluation, and Selection (TIES) process in the next section satisfies much of this requirement.

Requirements development begins with Warfighter input and ends with establishment of formal requirements. The TIES process works best when it solicits information from all sources in appropriate forums. Actively seeking participation by analysts, military users, industry, engineers, academia, and others in the life cycle of a technology is a best practice that can have high return on investment. Soliciting and getting participation from a broad network is the first step in developing better processes. These networks can help in articulating and refining requirements, which in turn helps in identifying technologies that maximize capabilities and minimize cost.

A four phase process for requirements generation that worked in a major ship design program is described below:

1. Prioritize attributes: In ship design, the Universal Naval Task List (UNTL) and Universal Joint Task List (UJTL) can be used as a starting point. Each task was prioritized by experts using an analytical hierarchy process and then each technology was rated as to how it contributed to the task. The life cycle cost of each technology was evaluated as well.

2. Trade study plan: The plan outlines the design features and sets of technologies that are to evaluated. This is like choosing different cars with numerous options packages to evaluate.

3. Cost and Performance Data: Once trade studies are defined, cost and performance data are generated with models and evaluated.

4. Requirements Documents/Specifications: Requirements are defined in terms of minimum and desired capabilities. This is one of the key areas to link to the RFP later in the program. Care should be made to preserve the details that are used to generate the top-level capabilities in the requirements document. These details should be used in the RFPs and source selection criteria. An example: Top-level capabilities are documented and each is described by up to eight attributes. Attributes are defined and described by up to six quantifiable metrics. Thus a very complex system may have eight top-level capabilities, up to 64 attributes, and over 380 metrics. The metrics should be included in the RFP and used as a framework for the source selection criteria later on in the program.

NOTIONAL REQUIREMENTS ANALYSIS PROCESS

One Navy program office put in place a technology evaluation methodology implementing the Quality Function Deployment (QFD) process to prioritize technologies. The overall process related a set of warfighting tasks to technology areas and then evaluated the programmatic aspects of each technology. To evaluate the programmatic aspects of the technology programs, a hierarchical programmatic objective model was established using seven programmatic top-level objectives defined by the Office of the Chief of Naval Operations (OPNAV) sponsor. The objectives are: Affordability, Statutory and Regulatory Guidance, Force Structure, Force Modernization, Risk, Technology Transition, and Industrial Base. Of these, Affordability, defined in this process as Total Ownership Cost (TOC), was weighted the heaviest in the model.

Each technology program was then evaluated against the programmatic criteria. The result was a prioritized list of technology programs, each with the appropriate mix of warfighting and programmatic objectives. Working with representatives from the Navy, the team first prioritized a set of warfighting tasks. These tasks were defined by the UJTL, which defines the strategic, theater, and tactical tasks for naval forces. The

list of tactical-level tasks was tailored to reflect potential tasks, then prioritized using a pair-wise comparison process.

The next step defined a set of performance attributes, such as speed, range, and vulnerability. Each attribute was then correlated to each of the warfighting tasks to determine the relative importance of the attributes in meeting the prioritized tasks. Likewise, a set of technology areas was defined and correlated to the attributes, one by one. This resulted in a set of prioritized technology areas which could be traced back to their impact on warfighting, through attributes, to tasks. Each technology project was then mapped to its most appropriate technology area.

Figure 3 shows a methodology for linking technologies to requirements and specifications used in a major ship design program. The team, consisting of functional experts and a group facilitator, used a QFD process. The approach used numerous pair-wise comparisons that were entered into software to prioritize technologies. This approach proved effective in the design phase for technology selection but was also very time consuming and expensive to implement.

The Defense Systems Management College (DSMC) teaches the technical community in its Advanced Production and Quality Management Course (PQM-301) that the QFD process is a highly effective way to:

- Capture requirements,

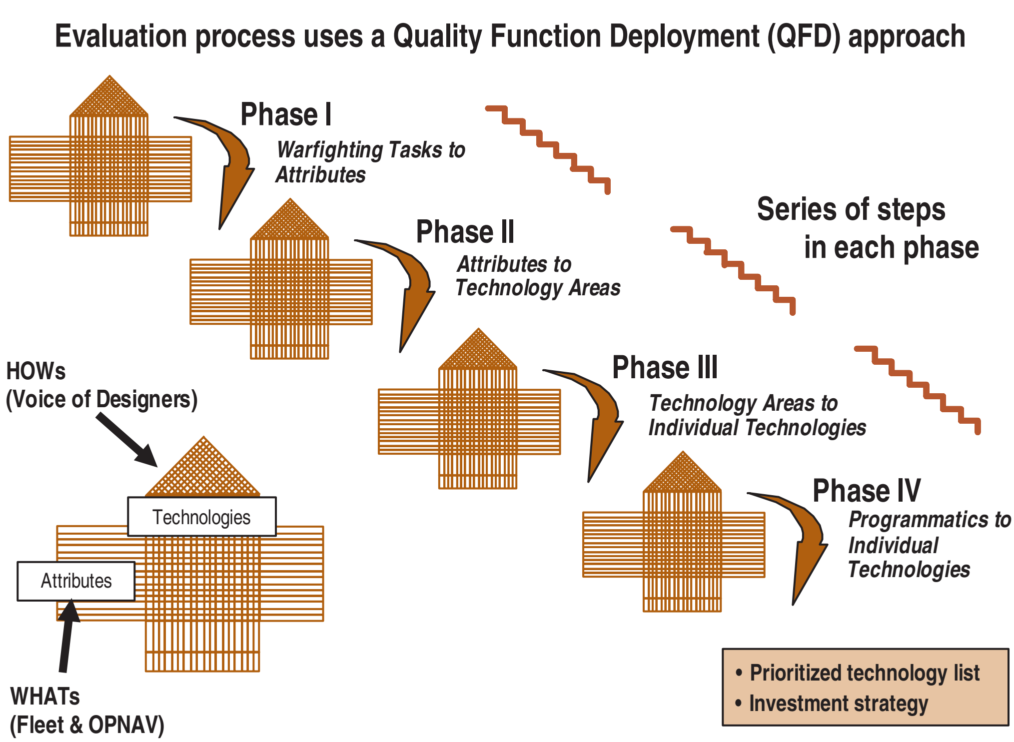

FIGURE 3. TECHNOLOGY EVALUATION METHODOLOGY

- Structure or respond to RFPs,
- Develop source selection criteria,
- Identify key areas for contractual awareness (incentive or award fee),
- Structure acquisition strategies,
- Manage the document and decision process, and
- Apply a structured systems engineering process.

Recently, the Office of Naval Research Affordability Measurement and Prediction Program completed development of a new generation of tools and techniques that integrate established techniques from private industry into what they call the Technology Identification, Evaluation, and Selection (TIES) Process.

The technical community uses the QFD to capture requirements and to structure the systems engineering process. The DoD application of QFD to structure proposals, develop source selection criteria, or set up contractor incentives is not wide. The application of QFD by program managers or contracts personnel is not widespread in the acquisition process for several reasons:

- The length of time between QFD application in the technical community and acquisition-related applications,
- QFD is not generally taught outside the technical community,
- Details of QFD do not reach the higher management levels,
- QFD can require large amount of resources, which may limit its application to larger programs, and
- Pair-wise comparisons of proposals in proposal evaluations are limited by regulations.

TECHNOLOGY IDENTIFICATION, EVALUATION, AND SELECTION (TIES) PROCESS

Recently, the Office of Naval Research Affordability Measurement and Prediction Program completed development of a new generation of tools and techniques that integrate established techniques from private industry into what they call the Technology Identification, Evaluation, and Selection (TIES) Process. The TIES process develops stronger and more integrated links between technology, requirements, design, and procurement processes. Its use in program management will result in a decrease in the time and cost to implement programs as well as facilitate better, more capable designs.

Cost-conscious industry and government personnel are very concerned with investment cost and risk associated with developing and infusing new technologies. Because of the focus on the bottom line, many companies and government development efforts dismiss new, innovative, and revolutionary designs due to the potential risk of profitability loss and budget constraints. A comprehensive structured process, applicable to any system, was needed to show companies and government designers whether a technology can be shown to improve a system at low risk. The TIES method was developed by the Office of Naval Research (ONR) and the Georgia Institute of Technology a few years ago to assess very aggressive vehicle concepts that could not meet cost and performance goals with present day technologies. The TIES process is a systematic approach to finding affordable technical solutions that quantify impacts in terms of performance, cost, and risk in the early phases of design. This method takes existing techniques from the various sources listed below and integrates them into the TIES method.

ESTABLISHED TECHNIQUES

- Response Surface Method (Biology, Operations Research)
- Design of Experiments (Agriculture, Manufacturing)
- Quality Function Deployment, Pugh Diagram (Automotive)
- Morphological Matrix (Forecasting)
- Multiple Attribute Decision Making (MADM) techniques (U.S Army, DoD)
- Uncertainty/Risk Analysis (Control Theory, Finance)
- Technology Readiness Levels (NASA)

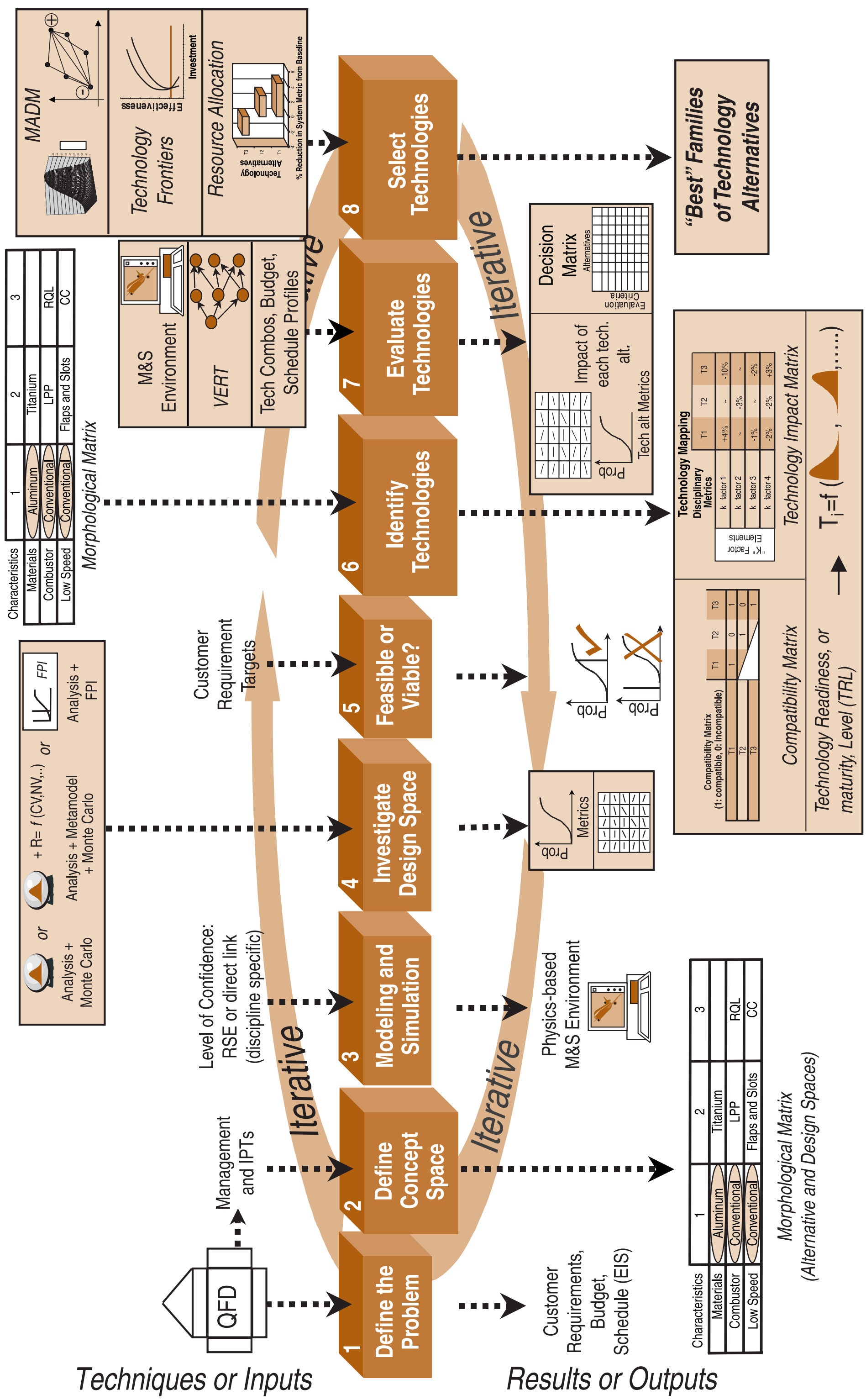

FIGURE 4. TECHNOLOGY IDENTIFICATION, EVALUATION, AND SELECTION (TIES) PROCESS

ONR INNOVATIONS

- Technology Identification, Evaluation, Selection (TIES)
- Proposal Evaluation Tool (PET)

Figure 4 shows the general structure of the TIES method and is intended to be a stand-alone flowchart to capture all aspects of the TIES method. The primary axis shows the eight main elements that compose TIES. It begins with problem definition and moves through technology selection that best meets customer requirements. Above the primary axis are various techniques or inputs suggested or required to accomplish each step. Below the axis are the primary results of each step.

THE PARETO ANALYSIS OF COST DRIVERS

A critical goal of many programs going through the milestone process is to balance cost constraints against desired performance enhancements. These traditional life cycle cost formats provide data in a summary fashion but provide little insight into variables which drive costs, especially at the system- or design-feature level. Thus, the data were useful to only some of the stakeholders.

A critical goal of many programs going through the milestone process is to balance cost constraints against desired performance enhancements.

The solution is to convert data to a system-level breakout. This is useful to both designers and decision-makers. The new comprehensive data structure facilitates a far more insightful view of the systems' life cycle cost drivers. In order to do meaningful analysis, traditional life cycle cost breakdowns should be decomposed into their subordinating elements and ranked by cost element, from highest to lowest cost. This allows one to identify (using the Pareto technique) the hierarchy of cost drivers at the ship system level. This information can play an important role in justifying a program investment strategy and determining the phasing of an acquisition strategy.

EVOLUTIONARY ACQUISITION STRATEGY

An evolutionary acquisition strategy is an excellent technique for a program to use when adapting its approach to a cost-constrained environment. The life cycle cost

analysis serves its most important function in providing the information utilized in developing evolutionary strategies. Initially, most programs start with a clean-sheet design or a one-step approach to a new design, but often the up-front cost precludes programs from being funded at desired levels in the near-term.

As an alternative to the clean-sheet approach, an evolutionary strategy of gradual change can succeed. A key concept in this approach is to invest in the top cost and performance drivers first, where the most significant cost reductions and performance enhancements can be achieved at the front end. Besides cost drivers, programs also must consider risk and technological maturity in determining an evolutionary approach. Thus, follow-on improvements can be made as risk reduction and technology maturation efforts become successful.

DESIGN OF EXPERIMENTS

In order for the program office to best utilize resources, it used principles of the design of experiments in developing its alternatives. The objective in design of experiments is to gain the maximum amount of knowledge with the minimum expenditure of effort. It was developed in the 1920s and is widely used in the industrial and systems engineering field and is one of the most powerful tools integrated into the TIES method. It creates product and process designs that are relatively "resistant" to variations emanating from manufacturing environment. Its key benefits include:

- Decreasing total engineering cycle-time,
- Improving the performance of key customer requirements,
- Creating product/process designs which are robust to any possible noise factors, and
- Improving the manufacturability of a product design.

Design of experiments helps to:

- Identify how feasible or viable the baseline concept is with respect to the constraints and objectives;
- Identify which constraints are hurting the baseline concept (i.e., "show-stoppers");
- Identify how much improvement is needed so that proper technologies can be selected for infusion; and
- Establish an optimal configuration for technology infusion.

With that in mind, a program office should create a design feature matrix that lays out groups of design features and technologies and assigns them to a select number of alternative concepts. The mix of technologies should be chosen to cover the range of capabilities and limit the number of alternatives that need to be studied. In this way, a program office can save time and effort by focusing on the most relevant concepts. The design feature matrix also links the performance requirements to proposed design features and technologies. The matrix should be a focal point for designers, cost engineers, and decision makers in the Analysis of Alternatives (AOA).

The Office of Naval Research Affordability Measurement and Prediction Program and Georgia Institute of Technology have developed a tool called Technology Frontiers that can help determine the best combination of technologies given design constraints.

The Office of Naval Research Affordability Measurement and Prediction Program and the Georgia Institute of Technology have developed a tool called Technology Frontiers that can help determine the best combination of technologies given design constraints. It identifies an ideal solution established from summation of "best" individual effectiveness parameters and alternative compromise solutions which also can be chosen depending on the priorities of decision-makers. This tool can improve the design of experiments and can reduce the effort in evaluating alternatives within program offices.

INFLUENCE AND IMPACT ANALYSIS

Perhaps the most difficult aspects to quantify in a program are the synergistic and negative effects technologies can have on each other and the total system. The concept of systems engineering was discussed earlier, where the goal is to optimize the total system rather that some of the parts. Complex systems can have many different alternative components. Each component can impact other elements of the system. One way to get started in understanding the interrelationships between requirements, technologies, costs, and functional areas is to develop influence diagrams. The goal of influence and impact analysis is to provide an effective means of specifying and evaluating new architectures for large scale complex systems. Integrated process teams can fill out influence forms for processes or systems. Utilizing these forms will

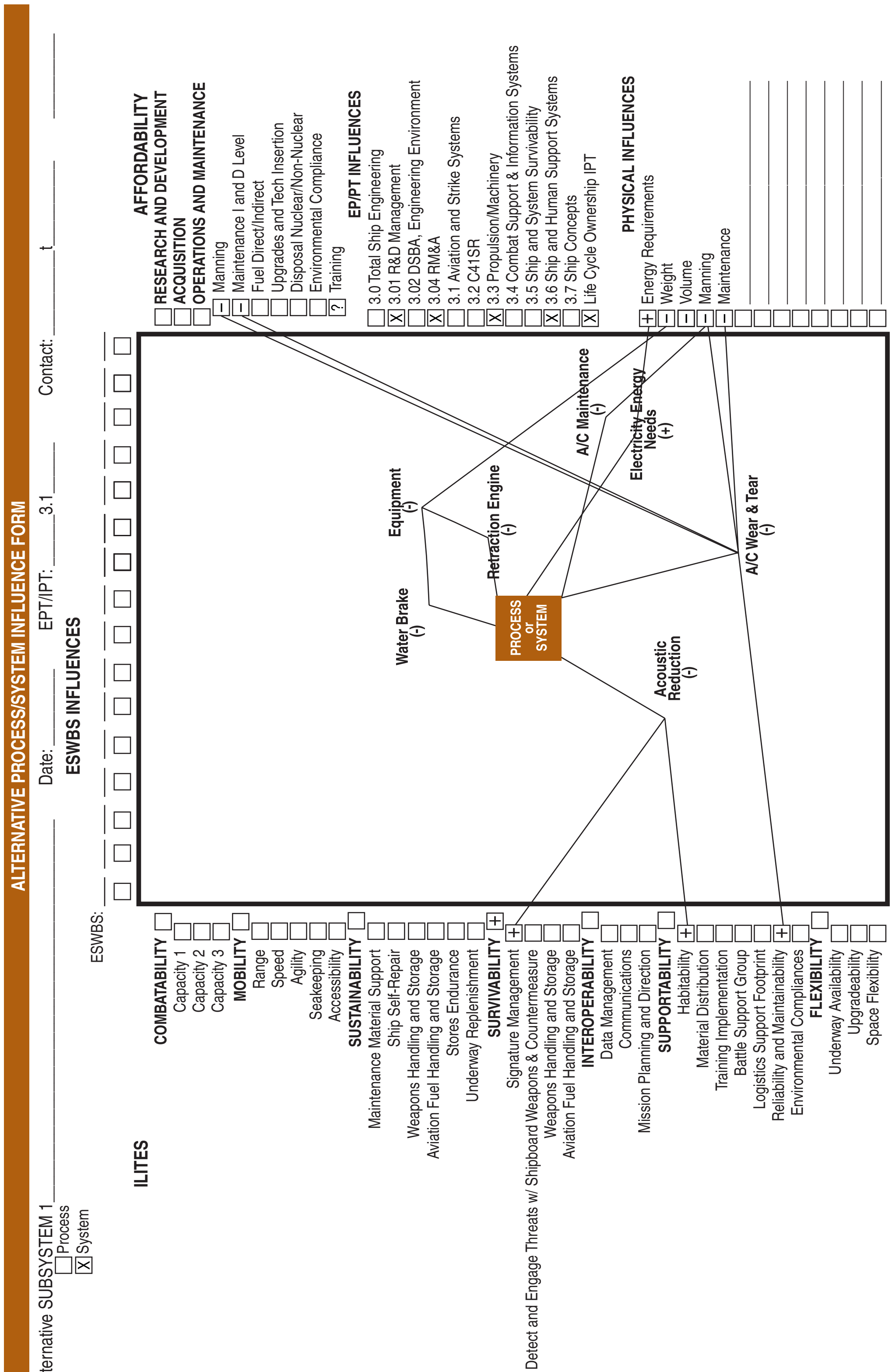

FIGURE 5. INFLUENCE FORM EVALUATING A SYSTEM

help focus each functional area on optimization of the total system rather than on its individual parts.

Figure 5 shows one type of influence form. The left side of the charts shows the capabilities and attributes that the requirements team generated. The top of the form lets you fill in what system level components are influencing an alternative. The right side lists the cost categories, Integrated Process Teams, and other physical characteristics that are influenced by the system. As you follow the lines inward, impacts are identified as plus or minus. This allows designers a first order look at the bigger picture and to consider the influence of their subsystem on other subsystems. The big payoff here is that the process of filling out this form can serve as a catalyst for functional areas to communicate more effectively.

PROPOSAL EVALUATION TOOLS

Proposal Evaluation Tools (PETs) such as Expert Choice, Logical Decisions for Windows, and ONR's PET are very effective in providing the framework for efficiently evaluating technology options that often are very complex with many permutations. The PET is a web-enabled decision analysis tool that facilitates evaluations of competing alternatives. The tool is able to automate much of the proposal evaluation process, conform to proposal evaluation regulations, and reduce proposal evaluation costs. It was funded by ONR and developed by Tecolote Research Incorporated. The PET is free to government users because it was developed using government funds.

PROPOSAL EVALUATION TOOL APPLICATIONS

The PET was applied to the NAVSEA Corporate Productivity Fund, other Navy Programs, and demonstrated its practical abilities in prioritizing multiple projects for evaluating and funding technologies. It efficiently allocated scarce resources to a number of proposals. Some Office of Naval Research codes have used it to help prioritize and select research projects to fund each year. The tool is unique because it allows the funding stream of many alternatives to be inputted and considered in its optimization sequences. The tool is suitable for formal proposal evaluations because it uses a question-based evaluation process, while also proving suitable for use in AOA. The application of the tools will be discussed further in the demonstration of results section.

BENEFITS OF USING THE PROPOSAL EVALUATION TOOL

The tool is easy to use and produces results. Setting it up gives structure to proposal evaluations, while significantly reducing the cost and time it takes for proposal evaluations and source selections. Evaluations can be done securely via the web or from a common server. Proposal evaluator travel expenses are eliminated if evaluations

are done via the secure web. Also, significant billable hours charged by evaluators are greatly reduced due to the efficient process and structure that emerge from using the tool. It can be used by any number of evaluators, which is important in large source selections. Evaluations are automatically updated and integrated so that leadership can see results develop in real time.

It also allows a decision maker to weight the decision variables when setting up proposal evaluation criteria and performing sensitivity analysis. Sensitivity analysis can be accomplished using both text and graphical displays. Decision-makers can view the evaluation scores of all evaluators. All top level scores, individual evaluator scores, and proposal scores can be viewed. The program also identifies and can display outlier scores. This allows decision makers to recognize blind spots, bias, or other issues that may not be identified using traditional proposal evaluation methods.

PROPOSAL EVALUATION TOOL METHODOLOGY

The PET uses an easy-to-follow methodology that can be done by individuals or through an integrated teaming approach. The method's basic steps include:

1. Defining the criteria and weighting their importance,

2. Determining the questions and scoring for answers,

3. Applying the questions to a set of proposals to obtain relative values, and

4. Prioritizing proposals by maximizing relative values using integer linear programming.

RESULTS OF PROPOSAL EVALUATION TOOL APPLICATION TO NAVSEA PROGRAMS

With two days' effort, the results of an AOA and prioritization of NAVSEA corporate productivity fund projects were reproduced with technical assistance from Tecolote Research. The PET first allows the input of pair-wise comparisons as a starting point, and then uses performance-based questions to develop relative rankings of alternatives. It is this second step that allows the analysis to transition from requirements evaluation to formal proposal evaluations. The results below show the analysis and illustrate the process and the outputs of the tool.

AOA ANALYSIS USING THE PROPOSAL EVALUATION TOOL

The AOA evaluated 70 different alternatives with eight capabilities, 31 attributes, and 177 metrics. These parameters were entered into the proposal evaluation, and

pair-wise comparisons were made to determine the relative importance of each parameter. The metrics were converted to performance-based questions whose answers could be scored.

Once all the criteria are evaluated for each proposal, the tool generates scores for each attribute. A color code is assigned to each attribute score based on user specifications. The tool then takes the raw scores and calculates the relative value of each alternative and displays them, enabling one to select the one best alternative.

There are other cases where multiple alternatives need to be selected within budget constraints. This is where the power of the PET serves to decrease evaluation costs and increase total value received. The next example illustrates this case.

NAVSEA CORPORATE PRODUCTIVITY FUND ANALYSIS USING THE PROPOSAL EVALUATION TOOL

The NAVSEA established a corporate productivity fund to facilitate cost saving initiatives within the organization. Each year, NAVSEA received hundreds of initiatives to evaluate. Proposals were submitted and evaluated in terms of technical benefits and cost savings, and the best ones were chosen and funded. The NAVSEA used commercially available tools to do the evaluations which proved to be a time-consuming effort. The fund was eventually disestablished and responsibility for cost-savings initiatives was allocated to lower levels in the organization.

The PET can be effectively used at any level of the organization. It facilitates standardized documentation of proposals and automates the evaluation and selection process. The example below takes the evaluation criteria used by the corporate productivity fund and applies it to some sample proposals. The details are omitted to place more focus on the capabilities of the tool.

Evaluation criteria and weighting were developed and proposals were submitted to be evaluated. This was followed by the evaluation and proposals being ranked by relative value. The criteria were that the cumulative cost of selected proposals could not exceed \$2.5 million and that the relative value of the proposal had to be greater than five. Thus, only eight out of the hundreds of proposals submitted met the criteria to be funded. This feature uses linear programming to determine the best set of choices. This methodology is a big time saver in evaluating and choosing proposals. The added benefit is that the computerized optimization program finds the best solution out of many combinations.

One feature that the PET automates beyond what is currently available elsewhere is its ability to do multiyear funding optimization. Given hundreds of proposals, it can develop spending plans across multiple years and projects. It is able to maximize total benefits while staying within yearly funding constraints. To do this it requires schedule information and funding limits for each project.

CONCLUSION

There is a need for improved technology management and proposal evaluation processes within the DoD. Training and tools need to reach the personnel who are designing and procuring our high-value weapon systems. It is hoped that this article will be a starting point in this endeavor and serve as a catalyst for future improvements. By using technical expertise to link capabilities to proposal rating criteria, the DoD can better use standards-based questions in RFPs that are based on detailed requirements documentation. Use of these tools will enable better designs, reduce labor costs, reduce time, and improve documentation. It will also enable better defense of source selections by procurement officials.

AUTHOR'S NOTE

For more information on the TIES method, contact Dr. Dimitri Mavris at the Georgia Institute of Technology or see the following Web site: www.asdl.gatech.edu

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